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(54) Title: SERIES WIRING OF HIGHLY RELIABLE LIGHT SOURCES
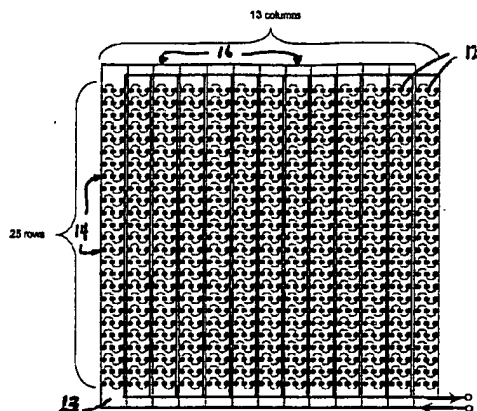
(57) Abstract: The light array of this invention includes a number of columns and rows of LED's connected in a series/parallel combination. The series parallel combinations effectively optimize the impedance, accommodate failure rate, facilitate light mixing, provide a means of imbedding redundancy, and common cathodes or anodes. This arrangement provides a superior light source for consumer, industrial and specialty markets in respect to mean time between failure, process control, radiant intensity, wavelength mixing, power requirements and other characteristics of the light source. Each column includes a number of rows of plural LED's. The LED's in each row are wired in series and each column is wired in parallel so that if one LED fails only the LED's connected in series with the failed LED will also fail. There is redundancy in the circuit as well as the arrays so that if there are failures different current carrying elements or different series LEDS will automatically by powered on. The array may be connected in series with one or more LED arrays to form a module. Multiple modules may be connected in series with other multiple modules.

For two-letter codes and other abbreviations, refer to the "Guid-ance Notes on Codes and Abbreviations" appearing at the begin-ning of each regular issue of the PCT Gazette.

SERIES WIRING OF HIGHLY RELIABLE LIGHT SOURCES

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5   This invention claims the benefit of co-pending U.S. Provisional Application No.

60/516,381, entitled "Series Wiring of Highly Reliable Light Sources," filed October 31,

2003, the entire disclosure of which is hereby incorporated by reference as if set forth in

its entirety for all purposes.

Background of the Invention

10   Solid state lighting devices such as, for example, light emitting diodes (LED's)

are used for a number of applications. One type of such solid state lighting device is

disclosed in International Patent Application No. PCT/US03/14625, filed May 28, 2003,

entitled High Efficiency Solid-State Light Source And Methods Of Use And

Manufacture, the details of which are hereby incorporated by reference.

15   There are numerous applications where a long string of devices, such as, for

example, LED's, need to be connected electrically. Such strings present unique problems

for the electrical engineer. On the one hand, there is a desire to string the components in

series so that the current from one component flows directly through the next component.

This is a desired configuration because it minimizes the amount of electrical current

20   required while increasing the total voltage required across all the components. Since high

currents are more difficult to deal with because high currents require large gauge wires,

for example, it is desired to have lower currents and higher voltages.

However, stringing the components together in series presents a problem because if one of the components in the string fails, it will result in the failure of the entire string. For example, in a string of holiday lights wired in series, if one light fails the entire string also fails. To overcome this problem, holiday string lights are typically wired in parallel

5   so that when one light fails the rest of the lights in the string continue to operate. However, such wiring requires higher current and lower voltage.

Wiring lights in series is preferred because the total current is lower and the operating voltage is higher. This presents a problem because if one light fails all lights in the series fail. Wiring lights in parallel overcomes this problem because when one light

10   fails all other lights still operate. However, one undesirable aspect of wiring in parallel is that the total current is higher and the operating voltage is lower.

One prior art approach to this problem is described in U.S. Pat. No. 6,153,980 (Marshall et al). This patent describes a circuit that has individual sensors for each light source and can determine if any given light source has failed. In the event of failure, the

15   circuit shunts current around the failed component so that the rest of the components that are wired in series continue to receive electrical current. While such a circuit solves the problem of allowing serial connection (and, thus, higher voltage and lower current) the circuit itself is more complicated, expensive, and prone to possible failure, which defeats it's intended purpose.

20   What is needed is a light source that never fails or that at least has such a high reliability and mean time between failures that failure is something that effectively can never happen. Thus, the preferred solution changes from parallel wiring to series wiring

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forming a cascading series parallel circuit substantially reducing failures and mean time

between failures. The parallel/series circuitry enables the selection of current and

potentials that can accommodate the specific performance of solid state light sources in

addition to complying with industry standards for different markets. These markets can

5   be, but are not limited to industrial (high power), consumer (low power) and specialty

markets as in the case of aerospace and medical markets.

Summary of the Invention

The present invention provides a light source that is composed of an array of

10   devices having a very large mean lifetime. The array is wired in a combination series and

parallel circuit that ensures that the composite device will virtually never burn out. The

light sources in the array of this invention are wired together in series without concern of

the consequences of a module failure.

The array of this invention may include a composite of LED's that may number in

15   the hundreds or about one thousand, for example. LED's are solid-state light sources

with very long lifetimes that are measured in hundreds of thousands of hours. The array

of this invention capitalizes on the lifetime of the LED's but also capitalizes on their low

operating current and voltage to produce a composite array that is partly parallel and

partly in series.

20   The light array of this invention includes a number of columns and rows of

LED's. Each column includes a number of rows of plural LED's. The LED's in each

row are wired in series and each column is wired in parallel so that if one LED fails only

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the LED's connected in series with the failed LED will also fail. The array may be
connected in series with one or more LED arrays.

Another advantage of the present invention is that connecting the LED's in series
provides all of the LED's in the series with the same amount of current so that the LED's
5   have the same brightness.

This invention provides a lighting module comprising an array of LED's
consisting of plural columns and rows, wherein each row of LED's in each column is
connected in series and each column is connected in parallel. The LED array may be
connected in series to one or more LED arrays. Each column in the LED array may
10   contain at least one row of, for example, three LED's. Each column in the LED array
may contain, for example, twenty-five rows of LED's. The LED array may contain, for
example, thirteen columns.

This invention also provides novel circuits for driving LED's. In one
embodiment, a circuit is provided that results in a high LED peak intensity without
15   requiring more power input. In another embodiment, a circuit is provided for pulsing an
array of LED's that results in very high current levels in the LED's without causing over-
dissipation.

These and other embodiments are described in more detail in the following
detailed descriptions and the figures. The foregoing is not intended to be an exhaustive
20   list of embodiments and features of the present invention. Persons skilled in the art are
capable of appreciating other embodiments and features from the following detailed
description in conjunction with the drawings.

Brief Description of the Drawings

Figure 1 shows an array of LED's that are wired both in series and in parallel.

Figure 2 shows a module of plural arrays of LED's wired together.

5   Figure 3 shows a full-wave bridge rectifier for directly driving a single string of LED's of Figs. 1 and 2.

Figure 4 shows a circuit for pulsing an array of LED's as shown in Figs. 1 and 2.

Detailed Description of the Invention

Representative embodiments of the present invention are shown in Fig. 1, wherein

10   similar features share common reference numerals.

As shown in Fig. 1, an LED array 10 is shown that is wired in a series/parallel combination. The LED array 10 includes a plurality of individual LED's 12 mounted on a substrate 13 and arranged in rows 14 and columns 16. Each column 16 includes plural rows 14 of LED's 12 with, for example, three LED's 12 in each row 14. There may be,

15   for example, twenty-five rows 14 in each column 16. The LED's 12 in each row 14 are wired in series and each column 16 is wired in parallel. Since the LED's 12 in each row 14 are wired in series it is ensured that if one LED 12 fails only the other LED's 12 in that series will fail also. The loss the LED's 12 in a single row 14 in the total array 10 has only a minimal impact on the total brightness of the array 10 since it consists of many

20   LED's 12.

In this example, the total voltage required to drive the LED array 10 is roughly three times the forward voltage drop across any given LED 12. The total current required

to drive the LED array 10 is 13ʹ25ʹXmA, where 13 is the number of columns 16 for each

array 10, 25 is the number of rows 14 of LED's 12, and Xma is the nominal drive current

required for each LED 12. For example, the LED 12 might have a nominal forward

current of 20 mA at a forward voltage of between 3.6 and 4.0 volts. For example, the

5   voltage and current for driving a single board populated with these LED's 12 may be

13ʹ25ʹ0.020A = 6.5A and between 10.8 – 12 volts.

    If all of the LED's 12 were wired in parallel, the required current would be three

times higher, and the voltage three times lower. The configuration of Fig. 1 provides an

improvement in offering considerably lower current at higher voltage while at the same

10   time producing an LED array 10 that has a virtually unlimited lifetime.

    Each LED array 10 may be wired, preferably, in series to one or more other LED

arrays to form a module as seen in Fig. 2. Multiple modules may be wired, preferably, in

series to other multiple modules. However, because of the virtually unlimited lifetime of

the LED array 10 the modules may be wired in parallel or in series without regard for

15   concerns that one of the LED arrays might fail causing failure of the whole module.

    For example, one might want ten LED arrays 10. Wiring them in series requires

(using the numbers from the above example) 6.5 amps at about 120 volts. This is roughly

the electrical requirement of a domestic vacuum cleaner. By comparison, if the ten LED

arrays were operated in parallel they would require 65 amps at about 12 volts, which is

20   roughly the requirements of a light-duty arc welder. So, when wired in series the

electrical requirements are far more tractable than when wired in parallel.

Thus, wiring in series results in lower current and higher voltage requirements. These requirements are more easily (cheaply and inexpensively) met by power supplies than having to provide higher current and lower voltage. However, as discussed above, series connections result in the entire string failing when any single component fails.

5   This is such a significant disadvantage that in almost all cases the wiring is done in parallel and the consequent cost in high current and low voltage is simply absorbed by the consumer.

With the LED array of this invention, a light source is provided that is made of distributed devices having lifetimes of hundreds of thousands of hours. The array 10

10   itself is wired in a parallel/series combination that ensures that if one LED 12 fails, at most only two others fail with it, as shown in this example. This is a minor problem for an array with hundreds of LED's 12. Except for row 14 of LED's 12 wired in series, the columns 16 of LED's are wired in parallel, ensuring that the LED array 10 can virtually never fail. It is this extreme reliability that allows multiple LED arrays 10 to be strung

15   together in series without regard for failure in any given array.

The number of rows 14, columns 16, and number of LED's 12 in each row 14 may vary depending on a number of factors such as, for example, the size of the array substrate.

Figure 3 shows a full-wave bridge rectifier for directly driving a single string of

20   LED's as shown in Figs. 1 and 2. A resistor may be used to provide a limit on current. One novel feature of this circuit is that no filter capacitor is used. The LED string conducts only on the peaks of the pulsating-DC output of the rectifier. The LED current

may be high, which may have an operational advantage in high peak light output,

particularly for chemical processes. However, the duty cycle is limited. The result is a

high LED peak intensity for the same power input. It is known that the human eye

responds to the peak intensity of a light source. The scheme of Fig. 3 results in a visible

5   light source of higher apparent brightness for a given power dissipation.

Figure 4 shows a novel scheme for pulsing an array of LED's as shown in Figs. 1

and 2. In this scheme, an AC-DC supply (shown here as an off-line rectifier) is used to

charge a low-ESR (equivalent series resistance) capacitor to a voltage much higher than

the low-current operating voltage of the LED. A string of LED's is placed in series with

10   a high-current MOSFET switch across this capacitor. If the MOSFET is switched to

"ON" at a duty cycle equal to or lower than 5%, it is possible to create very high current

levels in the LED's without causing over dissipation. Since the LED output is

proportional to current in the LED, the resulting peak optical output of the LED is many

times its DC value. This can have advantages both in visible and chemical systems

15   applications.

An LED can be electrically modeled as a diode with a series resistance. Pulsing

the LED in the manner described overcomes the series resistance and allows the current

in the LED to be determined by the usual diode equation:

$$I = Is \exp (V/kt),$$

20   where I is the current in the LED, Is is the saturation current, V is the voltage applied

across the diode junction (not the LED), k is the Boltzman constant, and t is the absolute

temperature.

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It can be shown that very high currents are possible in an LED junction if the series resistance can be overcome by high-voltage pulsing means. Voltages across individual LED's can be in excess of 20 volts for a 3-volt junction voltage. The actual construction of the individual LED will determine how high the applied voltage can be before voltage breakdown occurs. As such, voltages considerably higher than a typical 3.3 volts may be applied to drive the LED's. Individual LED's may be pulsed with voltages of between 6-50 volts. However, voltages up to 150 volts may be applied to the LED's. It is also possible with this invention to pulse at least one LED up to 1,000 times its DC current value.

Persons skilled in the art will recognize that many modifications and variations are possible in the details, materials, and arrangements of the parts and actions which have been described and illustrated in order to explain the nature of this invention and that such modifications and variations do not depart from the spirit and scope of the teachings and claims contained therein.

While the inventor understands that claims are not a necessary component of a provisional patent application, and therefore has not included detailed claims, the inventor reserves the right to claim, without limitation, at least the following subject matter.

WHAT IS CLAIMED:

1. A lighting device, comprising,

    an array of LED's consisting of plural columns and rows, wherein each row of

    LED's in each column is connected in series and each column is connected in

    parallel.

2. The lighting device of claim 1, wherein the LED array is connected in series to

one or more LED arrays to form a module.

3. The lighting device of claim 1, wherein each column in the LED array contains at

least one row of one or more LED's.

4. The lighting device of claim 3, wherein each column in the LED array contains at

least two or more rows of LED's.

5. The lighting device of claim 4, wherein the LED array contains at least two or

more columns.

6. The lighting device of claim 1, wherein the LED's connected in series are

supplied with the same amount of current so that each LED emits the same

brightness.

7. The lighting device of claim 1, wherein each of the two or more LED's in each

column is also supplied with the same amount of current so that each column emits

the same brightness.

8. The lighting device 3, wherein each module is connected in series to one or more

modules.

9. The lighting device 3, wherein each module is connected in parallel to one or more modules.

10. A method of making a lighting device, comprising,

    providing an array of LED's consisting of plural columns and rows,

    wiring each row of LED's in each column in series, and

    wiring each column in parallel.

11. The method of claim 10, comprising,

    connecting the LED array in series or parallel to one or more LED arrays to form a module.

12. The method of claim 10, comprising,

    providing the LED's connected in series with the same amount of current so that each LED emits the same brightness.

13. The method of claim 10, comprising,

    providing the LED's connected in parallel with the same amount of current so that each LED emits the same brightness.

14. The lighting device of claim 1, wherein the LED's are driven by a full-wave bridge rectifier circuit.

15. The lighting device of claim 1, wherein the LED's are driven by a circuit in which an AC-DC supply is used to charge a low-ESR capacitor to a voltage that is substantially higher than the low-current operating voltage of the LED.

16. The lighting device of claim 15, wherein a string of LED's is placed in series with a high-current MOSFET switch across the capacitor.
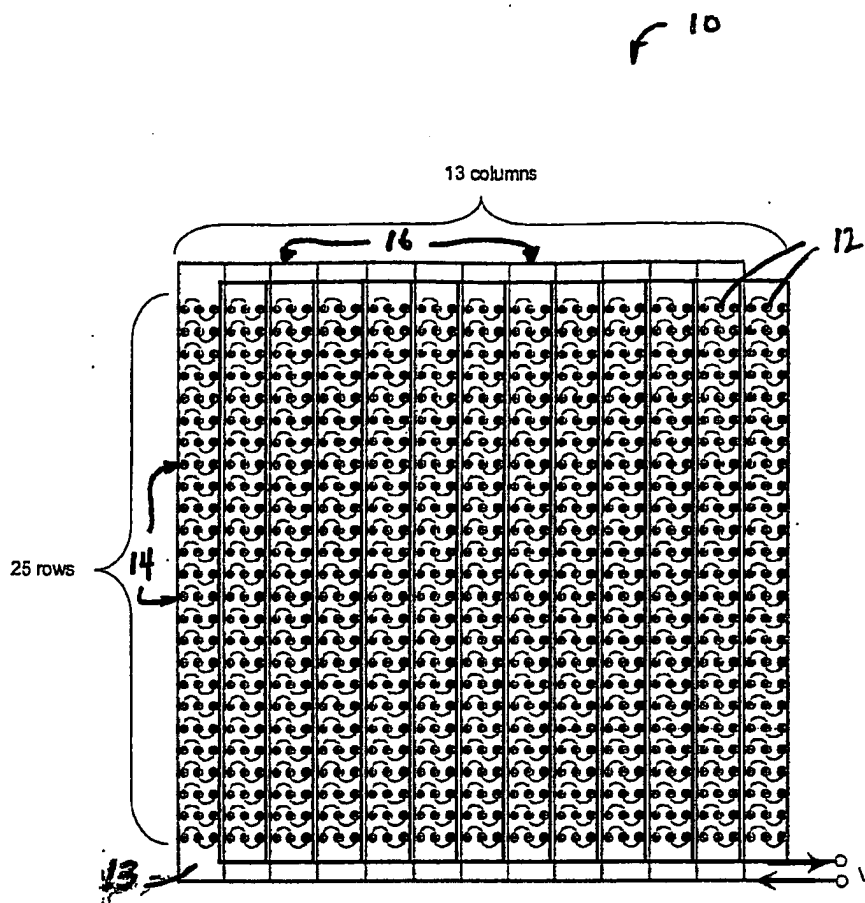
17. The method of claim 10, wherein the LED's are driven by a full-wave bridge rectifier circuit.

18. The method of claim 10, wherein the LED's are driven by a circuit in which an AC-DC supply is used to charge a low-ESR capacitor to a voltage that is substantially higher than the low-current operating voltage of the LED.

19. The method of claim 18, wherein a string of LED's is placed in series with a high-current MOSFET switch across the capacitor.
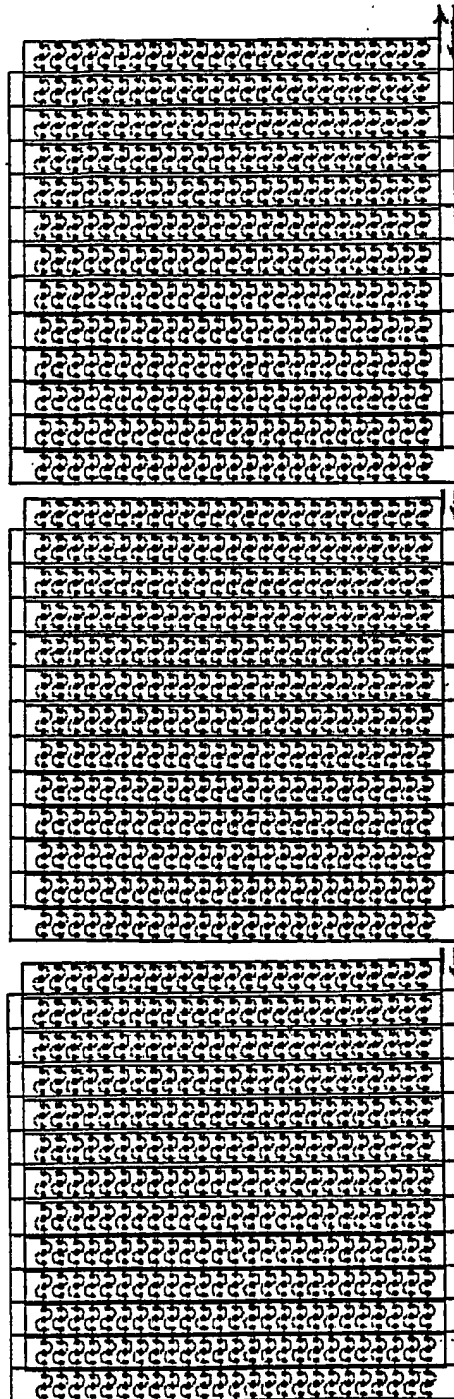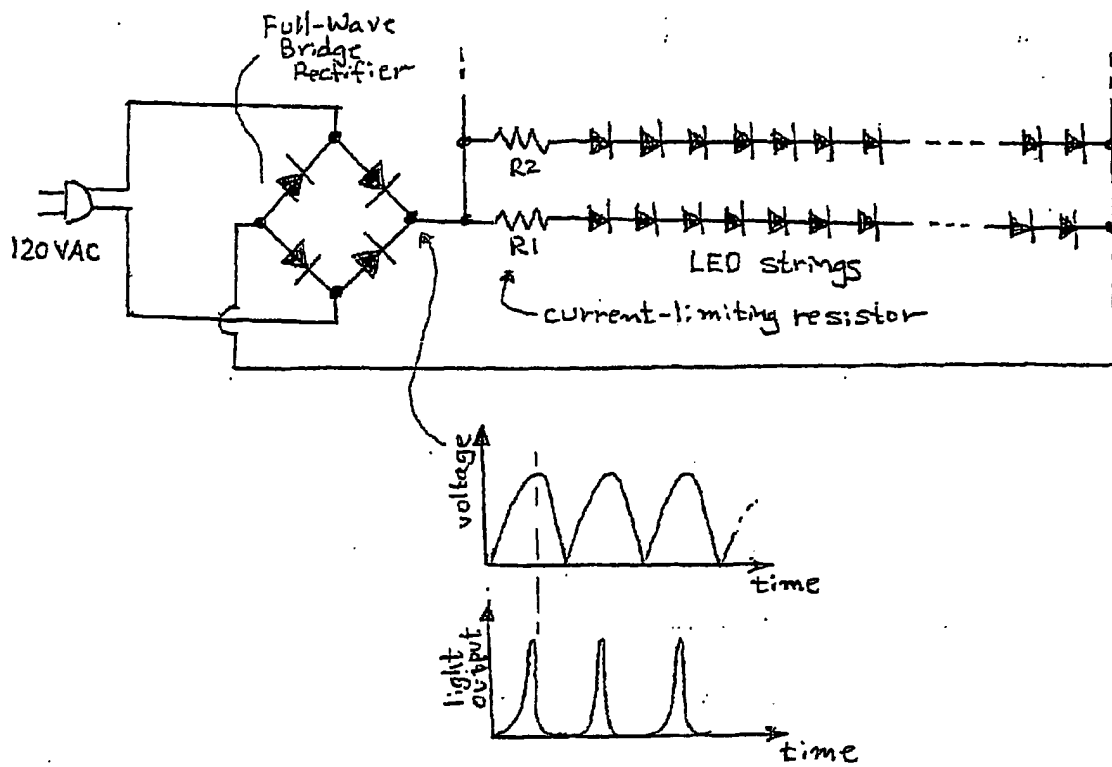
10

13 columns

16

12

25 rows

14

13

V

FIG. 1

FIG. 2

FIG. 3

FIG. 4